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CONTENTS

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A PLEA FOR THE BROADER EDUCATION OF THE CHEMICAL ENGINEER[1]

IT has become my duty, under a provision of the constitution of the American Association for the Advancement of Science, to mark my retirement from the office of vice-president and chairman of Section C by an address. Sir Boverton Redwood remarked on a recent occasion that such addresses offer an opportunity for the dissemination, from time to time, of highly specialized information. I might follow this custom and talk to you about one of the chemical industries in which I have specialized, but these subjects are of such limited interest that I shall avoid them and turn to one which appeals to me as being of the greatest importance at the present time, although, at first thought, it may seem to have received sufficient consideration of late, in view of the address of my predecessor in office, and many others, on the same and allied subjects. I believe, however, that no apology is necessary for asking your attention to the subject of the education of the chemical engineer, and this will include what he should be in the light of what he will be called upon to do, what characteristics he should possess, how he should be directed and encouraged, what training he should submit himself to in order to meet the demands which will be made upon him, and, finally, how his profession may be raised thereby to the level of the other learned professions such as

[1] Address of the vice-president and chairman of Section C—Chemistry—of the American Association for the Advancement of Science, Chicago meeting, December 31, 1907.

law, medicine and civil engineering, as exemplified by their most successful practitioners and representatives, since it is not too much to hope that it may, in the near future, be elevated to a place of due honor and prominence and given proper recognition in our national life, and that, eventually, the chemical engineer may fill many of the executive and administrative offices of our largest and most important industries.

That our industrial progress within the last half century has been phenomenal is too evident to require mention. Much of it has been based, however, on a very wasteful use of our natural resources, and, with their approaching exhaustion, reforms must be instituted and economies practised. There is a marked demand for an improvement in the quality of the output of some of our industries. The field for invention of new processes and new products is large. That the chemical engineer will play a large part in the development and regulation of the industries of the country along these lines can not be denied. It is already evident in what he has done in connection with the use of the electric current available at Niagara Falls and elsewhere. He has become, and will remain, the mainstay in certain particulars of the regulation and development of our many industries.

President Stone, of Purdue University, has said:

> True industrial progress consists in utilizing with ever-increasing economy and accuracy, natural forces and materials by more scientific methods of operation and management, in securing better conditions of life for industrial workers, in furnishing products of better quality at lower cost, and narrowing the gap between the employer and the employee.
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> There comes a time inevitably when the mine is empty, the forest destroyed, the virgin soil exhausted. Then will arise the real question of industrial ability which can only be met by education and training.

As the chemical engineer will have a large part in solving this problem and as the demand for his services must increase to a great extent, it becomes an important question as to how he shall be selected, educated and trained to fill the rôle which he will have to play. It is this question which I wish to discuss to-day in the light of the opinions which have been expressed by others, and in that of my own experience, the latter being that the graduate of our technical and scientific schools who proposes to adopt the career of chemical engineer is the product of a too narrow training, being at the best an expert chemist, and in no sense fitted to deal with affairs or impress himself upon others. My plea will be for a broader education for the young man who proposes to become a chemical engineer, and for avoiding the making of the intense specialist with his narrow point of view and lack of culture. My remarks will be addressed as well to the young man who is contemplating entering upon such a career, or is already in preparation for it, as to those who will be responsible for his training, or, as industrialists, look forward to the advantages to be derived from having available broad-minded, liberally educated and cultivated men who are, at the same time, chemists and men of affairs, and, as such, fitted to take part in the development of our industries.

We must formulate our idea of what constitutes a chemical engineer. In my opinion, a chemical engineer is, primarily, a chemist, but essentially a man of affairs and executive ability who is engaged in the application of the principles of chemistry in the arts and industries, with special reference to the commercial development of the industries and establishment of new ones, to perfecting the arts, and by his advice and cooperation, assisting other engineers in the practise of their professions.

There are, of course, many types of chemical engineer: the inventive type, in some ways the highest; the type which adapts and makes practicable the discoveries of the inventor; the administrative and economic type, which is that of a large number of the profession; the constructive type, dealing principally with the design and construction of apparatus and plants, and approaching more nearly the civil and mechanical engineer, and, finally, the advisory type, which is engaged almost entirely in a consulting and inspecting capacity, and who more nearly resembles the counselor at law and is closely allied with him in litigation involving facts or opinions which must be interpreted in the light of chemical principles or experience. The type into which any individual may develop will depend upon his temperament and aptitude and upon the opportunities which he may have opened to him.

The mere technologist or industrial chemist is often confused with the chemical engineer, but should be sharply distinguished from him. The former is merely acquainted with the details of the various arts and industries, as they are carried on at present, and he sees that they are properly conducted according to rule and custom. He does not originate, nor does he study them from the point of view of the chemical investigator. He is more nearly an empyric. He is unable to meet the demands which are made upon the chemical engineer, or to take a leading part in the affairs of the world.

The chemical engineer must not be content to remain a mere technical man. He must be practical. As President Humphrey has remarked of the civil engineer: "His work must be based upon correct and complete theory, but it must be, first and last, practical," while Professor John Perry calls attention to the fact that:

> He must have all the knowledge of the scientific man, and ever so much more. He uses the methods of the scientific man and adds to them methods of his own. . . . They come to him through a very wide experience of engineering processes, of acquaintance with things and men.

We should have in the chemical engineer, at once, the thorough chemist, the man of imagination, the leader of men who inspires confidence in those about him. He should be an executive of the first order, who, having an eye for the selection of others of a capacity for special duties, is able to direct them so as to obtain the greatest return from their services. He should not waste a moment's time in doing anything which another can do equally well, and should reserve all his energies for the higher problems which may be met. He should have tact in dealing with others, and, in particular, should be able to express himself by word of mouth and in writing in a forceful manner, that is to say, he should have command of the English language and some literary capacity. He should also have a knowledge of German and French so that the scientific literature of these countries may be available to him and enable him to keep in touch with the specialists who are at work there in his own and allied professions. He must be at all times a student and a wide reader. He should not neglect research and should inspire his subordinates with the necessity of it for the prevention of that tendency to fall into a rut which is so common. He should be a man of personality to enable him to make a favorable impression upon those with whom he is brought in contact. He should avoid all antagonisms and should only permit himself to indulge in destructive criticism on rare occasions. Above all, he should possess initiative, imagination and perspective. He should be a person of original ideas and not a mere follower of those of others. He should not be afraid of the improbable and the unlikely, and, in this respect, may well

take to heart the advice of Sir William Ramsay.

For the making of the successful chemical engineer, as for other professions, the best material only is suitable, if the result is to be more than mediocre. Unfortunately, the human race is not bred to points, either physically, mentally or for special aptitudes, in the same way that is practised with the race horse, with high-grade cattle or dogs, to develop their most desirable characteristics; the importance of national eugenics has only recently been brought to our attention by Galton and Pearson. We have recourse, therefore, only to what chance may produce. Nevertheless, chance has done much for us. Professor H. E. Armstrong calls attention to the fact that:

> Americans may be said to be a distinct if not an improved breed. Certain proclivities have been, undoubtedly, unconsciously selected out and there has been much cross-breeding; hence a race has developed differing in important respects in its type of thought if in no other way, from those represented in Europe. Moreover, success has given them belief in themselves, and leads them to trust themselves.

We should make our choice of those youths who have had the best of home discipline and restraint. Sir John E. Gorst calls attention to the fact that:

> The chief causes which produce formation of character are met with in the homes of the people.

The individual who has been subjected to the most favorable environment in his early years and in the secondary schools will be the most satisfactory, if he possesses the proper aptitude to be a chemical engineer.

Aptitude, or what is sometimes denominated a natural gift, is inborn and must be sought out. It can not be developed, but may be encouraged and directed. Professor A. Lawrence Lowell, of Harvard, has wisely said that the problem of the schools is to discover and stimulate the right kind of men more than to directly instruct them. There is too great a tendency to attempt to make chemical engineers out of all who have a fancy for dabbling in a laboratory. For this reason, it seems to me, a great responsibility rests upon our schools in guiding the youth into proper channels and restraining him from fields where he can only meet with disappointment.

Taking what chance may offer as regards breeding, and chance at times offers very good material if we exercise selection, we must endeavor to impart direction from the earliest years of the individual's training.

> It is for wise direction that the coming generations cry; and it is our business to see that they get it,

as the man of science remarks in "A Modern Symposium."

In our secondary schools there is too little consideration of the individual or of his direction. There is too much routine, too much system and uniformity. The bright and the dull boys are advanced through the various grades at the same rate. What we need is, as stated by President Eliot, the promotion or advancement of each pupil by subject and not by mere time. By the present system, much time is lost to the bright boy. Individuality, and not uniformity, should be the rule in all branches of education, and particularly in the case of those who propose to become professional men. Dr. Böttger appreciates the situation in our American high schools when he says:

> In America one finds the object of the high school instruction to be to enlarge the capacity of the average man, while in Germany the main object is well known to be the complete development of the best student.

While this object is a praiseworthy one as applied to the average man in America, it is not satisfactory in the case of those who propose to follow a professional career. President Remsen, however, in reviewing

Böttger's book, thinks that while it may be true of our colleges and technical schools, it is wrong as regards the graduate work of our universities, and this is probably true of our graduate schools of the higher class, but plainly not so in those which turn out some of our weaker doctors of philosophy.

Hugo Münsterberg points out, in a way well worthy of consideration, some of the faults of our secondary educational system. He says:

I do not want to be misunderstood as seeing no fault in the American system of instruction. There are not a few wrong tones which hurt the ear of the newcomer, discords to which he will never become insensible. But these fundamental errors belong to the school rather than to the college. It is enough to point out the most devastating one; the lack of mental discipline at the very beginning of the intellectual growth. The school methods appeal to the natural desires and do not train in overcoming desires; they plead instead of commanding, they teach one to follow the path of least resistance instead of teaching to obey. The result is a flabby inefficiency, a loose vagueness and inaccuracy, an acquaintance with a hundred things and a mastery of none. Public life has to suffer for it, a community which does not get a rigid mental discipline through home and school influence must always remain the plaything of the lower instincts.

How much more the American college might have been able to produce if it could have received into its freshman class young disciplined minds, trained in accurate and careful learning and in the restraint of primitive impulses. The college would not have been burdened by wasting much of its costly time in repeating the elements of learning and patching up the slang-disfigured English language.

Professor C. A. Waldo, in his vice-presidential address before Section D of the American Association for the Advancement of Science at St. Louis in 1903, on "The Relation of Mathematics to Engineering," said, dealing with the question of our preparatory schools:

This is the indictment of the schools, that they use, largely to the exclusion of the thought element, a mass of formal and conventional educational material and thus paralyze thought and make abortive any natural mental growth.

Professor J. J. Stevenson remarks (*Popular Science Monthly*, January, 1904):

The old adage says: "He who would command must first learn to obey." That American lads are sorely in need of such training is only too evident. . . . Such training means—training to think, to reason. Lads often fail to receive this training in secondary schools, as any instructor who has had to deal with freshmen can testify. Secondary schools to-day are little better than cramming houses to fit pupils to answer odds and ends of questions in papers for entrance examinations. Loose training and restlessness under restraint characterize the American students in the lower classes at college; lack of home training may be in part responsible for the latter characteristic, inferior teaching in secondary schools for the former.

There is much of truth in the preceding assertions. Our secondary and high schools are unsatisfactory. They offer to the colleges a mass of more or less unformed material which must be worked over again at great loss of time and energy. It is evident, therefore, that one of the first steps in the improvement of the education of the chemical, or, in fact, of any engineer, lies in a modification of his early training.

If we can not expect as much as might be desired from the secondary schools, we may at least study the material that is offered, selecting and directing that which is most suitable for encouragement, but we must not force the crude product into the professional schools. That, it seems to me, is the great crime of to-day, especially in the case of those who propose to become engineers of any type.

What provision can be made to avoid these difficulties? I believe this lies in postponing professional training except in so far as elementary science may form a part of any ordinary liberal education, until a proper foundation can be laid for it. We do not find at universities of the

highest standing that students are received into the schools of law or medicine until they have prepared themselves for the study of these professions by a liberal education involving the taking of a bachelor's degree, which is accompanied by the attainment of the necessary degree of maturity. Is chemistry as a profession one which does not need the same foundation? In my opinion, this is not the case. A sound foundation is quite as much needed as in law or medicine.

The subject has been discussed, pro and con, at great length in numerous recent addresses. Professor George F. Swain, in opening a discussion on engineering education before the American Society of Civil Engineers in 1906, said:

Most people will admit to-day that civil engineering, like other branches of engineering, belongs to the learned professions, and should require a preliminary training corresponding to that necessary for the lawyer or physician.

The trouble with the young man between the ages of sixteen and twenty-two, who is given the opportunity of a higher education, is that he fails to realize his opportunity and does not take advantage of it, and, as a result, many of the graduates of technical schools and colleges have neither accurate knowledge of any one subject, nor the ability to think clearly and logically, nor the power of taking up a new subject and mastering its fundamental principles without assistance. . . .

In laying out an engineering course, the aim should be, first of all, to develop broad-minded men who can observe correctly, reason logically, express themselves in language and on paper, men with imagination and with character, and with good physical development.

He adds:

Studies which involve discipline of the mind and observation should be preferred to those which merely give information.

Subject to the above restrictions, what is taught is not as important as how it is taught.

The choice of a profession should be made as early as practicable and a continuous course should be arranged with that profession in view from the beginning of the higher education.

Professor Hugo Münsterberg in a recent address at Lafayette College, already referred to, in which he sings a song of praise for the American college and advocates the establishment of one in Germany at Hamburg, says:

The idea was that in Hamburg, just as in Harvard, the youth ought to get in common, in years of academic freedom, the inspiration of cultural work in history and economics, in literature and philosophy, in art and natural science, before their ways are divided to go either to the professional schools of the typical German university or to the practical enterprises which commerce or industry or agriculture or politics may offer.

That which is needed for the Germany of to-day, and still more for the Germany of to-morrow, is an academic institute of a new type—a university where the full freedom of academic life can be joined to studies of a purely cultural character, where young men may enter two years before they have reached the present goal of the professional university, and where a three or four years' course would prepare them for the duties of life without any thought of their later occupation.

He adds that in America:

Public opinion was thus imbued with the correct idea that these professional studies did not in themselves guarantee a high level of culture. The real culture, on the other hand, the making of a gentleman, was left to the college. . . . The highest professional schools to-day demand the bachelor degree at their threshold.

If Professor Münsterberg demands something of the sort for Germany, why should it not be put to greater use in the education of our chemical engineers in this country, where it can be had for the asking?

The board of visitors to the Military Academy at West Point for the present year appreciated the necessity of overhauling the curriculum at that institution, with a view to bringing about a broader culture, the course now evidently being too intensive. The board states:

An officer of the army should be an all-around educated gentleman. As it is now, his entire training, both preparatory at the academy and postgraduate, is almost purely technical,

and within a few weeks President Schurman, of Cornell, has emphasized the impor-

tance of such considerations in his annual report for 1906–7.

In an address, well worthy of careful consideration, before the graduating class of the Rose Polytechnic Institute in 1903, Dr. C. E. Mendenhall, of the University of Wisconsin, discussed the subject of whether the technical education there given compared favorably with the so-called liberal education of the regular college or university. He concludes:

> It is apparent, then, that technical education, as at present understood, is strong in the matter of the discipline of the mind and will; it will help a student to think clearly; it will give him self-confidence and self-control, and teach him the virtue of the necessity for work. It is equally apparent that the system is weak on the side of broad general knowledge and cultivation, and there is no doubt that this is a serious defect.

And after discussing various remedies for the situation, he adds:

> In ways like these will it become more and more true, let us hope, that the engineering graduate has had the essential features of a liberal education in addition to his professional training.

He asks the question:

> But do we fully grasp the fact that we are called upon to be broad men as well as specialists, and that there is a sort of success to be attained quite distinct from our professions?

The president of Case School, in his inaugural address in 1904, said:

> It [a technical course] does not teach him all that an educated man ought to know. It would be much better if our technical graduates were broadly educated men as well as trained engineers, if they had received a college training before entering on a technical course. . . . I believe the student should be trained to know, to search, to think, before he enters the technical school. During his whole life he would have a broader outlook, a deeper sympathy with men and events, a greater influence upon the community. I am sure he would be a better engineer.

President James, in his inaugural address on assuming the office of president of the University of Illinois, in 1905, said:

> The university is the institution which furnishes a special professional, technical training for some particular calling. This special, technical, professional training must, however, be scientific in character and must be based upon adequate preliminary preparation of a liberal sort.
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> By this requirement of a liberal preparatory training, the university is differentiated from the technical school or trade school of secondary grade.

In the light of the preceding statements, it would seem that my plea for a broader education of the man who is to adopt a professional career has been supported very generally by those who have given the subject consideration. The requirements of the Harvard Schools of Medicine and Law are recognized as applicable to other professional schools, and in this respect I am putting forward nothing novel. I believe, however, that but little has ever been said in regard to the necessity of a similar requirement in the schools where our chemical engineers are trained, although an equal necessity, in my opinion, exists. I am ready to grant that the individual who proposes to follow the career of an investigator in pure science may, perhaps, succeed by specializing from his earliest years, but it can not be granted in the case of the engineer who must train himself as well to deal with men and affairs as with his strictly professional subjects. The question, of course, always arises as to what the education shall be of those who are to occupy places of minor rank, and form the rank and file of industrial chemists, but who will never attain eminence as chemical engineers. Here a good education is demanded along technical lines alone, and in the more narrow field little else is called for. Our technical schools can accomplish this work, but there is always danger that the graduate may be led to think that his degree, without any regard to his natural abilities, will lead him to the higher places in the profession, and, when he finds that he is not the great success that he has pic-

tured to himself, he blames the system of education, and not entirely without cause. There are too many graduates of the technical schools, especially of the middle west, who are spoiled by being educated beyond their capacities. They would be better off with a good high school education and with a trade. This, however, is a different problem from that which we are considering. What we must take up is: how can the student of sufficient capacity obtain the training and education for which I have pleaded? It will, of course, involve the expenditure of more time and money than if the mere technical training is sought. If time and money are insuperable objections, the more satisfactory course must be abandoned, and reliance placed upon the possibility of making up the deficiencies in the school of application in after life. It is my belief, however, that great efforts should be made to follow the course which I have laid down. On its completion, the man will find himself a more matured and better informed person, he will have greater confidence in himself, he will make a better impression on those with whom he comes in contact, and will command a greater remuneration. He will find that he is well repaid for the effort which has been made. Of course, in the case of the individual who is not hampered for means or time, there can be no question, for the same reasons, as to what to do.

It has not been the usual course for the chemist as yet. It approaches more nearly to that of the college graduate who, with the A.B. degree, spends three or more years in obtaining a Ph.D., and, as far as a knowledge of chemistry is concerned, such a course would be satisfactory. As Professor L. M. Dennis has remarked:

> There should be no distinction between the training of the technical chemist and one who is to devote himself to pure science and investigation.

The chemist who is to become a chemical engineer, however, must also be equipped in other ways which can not be done in the mere attainment of a doctorate. He must acquire his professional attainments in a different school and atmosphere. He must perfect himself in allied subjects and be competent to cooperate with other engineers.

My own idea is that the plan offered by Harvard will furnish the most desirable training for the chemical engineer, whether practised at that university or elsewhere. At Harvard, on the point system, a liberal education and the bachelor's degree can readily be attained in three years by one of slightly more than average ambition. During these three years he will have been subject to an environment which will mature and broaden him if there are any broad qualities to be brought out. He will find himself and his capacity, and how to direct himself. He can, in addition to the liberal courses which he may take, select such others as will enable him to satisfactorily enter the graduate school of applied science and to there pursue his technical studies. He is in a position to take up the professional work of the school with every probability of approaching it as a mature and well-balanced man. Two years in this school is rewarded with the degree of master of science in chemistry, and the graduate is then ready for more advanced studies or for entrance into the final and great school of application.

At the present time the number of students in the graduate school of applied science at Harvard is sixty-three, of which, I regret to say, only one is a student of chemistry. This is not large as compared with many of our scientific and technical schools, but the quality of the men enrolled, and the number of undergraduates in Harvard College who look forward to entering this school later, and are planning their work to that end, is so large that the cor-

poration of Harvard is entirely satisfied with the experiment that it has made. It is, in fact, so well satisfied that within a few weeks it has definitely committed the university to the policy of placing the technical work in the university on a graduate basis, and it has closed the Lawrence Scientific School to the further admission of new students.

It is evident, therefore, that Harvard University has made a very great step in advance along the lines which I have suggested for the preparation of the individual for professional studies and fitting him to become a chemical engineer. It seems to me that it will acquire the same reputation from its move in this direction as it has in its law and medical schools.

At Columbia a similar course can be pursued, taking the B.A. in the college or the B.S. in the scientific school after four years' study and then proceeding in two years to the degree of chemical engineer.

Johns Hopkins has a graduate school of applied science, largely devoted to research, while in 1903 the Massachusetts Institute of Technology issued a prospectus for a graduate school of engineering, leading to the degree of doctor of engineering, which has not, as yet, materialized to any great extent, but which we may hope to see encouraged under the direction of the present acting president of the institute, our colleague, Dr. A. A. Noyes.

There are, no doubt, equally satisfactory opportunities in other schools for such a training as I have demanded, if the desire for it is expressed, and I would by no means suggest that continuous study in any one locality is necessary or even desirable.

The instruction in some of our schools is intensive, in others, broad. In one, the student meets an environment which is purely local, in so far as all, or the majority, of the instructors are graduates of the school in which they teach. In another, they have been assembled from a wider field, have brought to the school a broader conception of the science, and a more liberal point of view. The latter is surely the more desirable. It is quite possible, therefore, that it may be as well to move from place to place for the change of atmosphere which may be obtained.

The main thing to be accomplished is the making of the liberal-minded man of broad intelligence who shall possess those qualities which I have cited as being necessary in the chemical engineer and which, in my opinion, are not found in the graduates of our technical schools as they are now thrown on the world.

If time and my confidence in your patience permitted, I might go at length into some other defects in our system of educating the chemical engineer, more especially as to the evils of examinations and of making undue exertions to obtain degrees. But these subjects must be reserved for another time and place. The views of many prominent persons in regard to them are well known to you, and I may add that I am in sympathy with the idea that they are both evils which need very careful consideration.

It is to be hoped that the suggestions which have been made, although in no way novel, may, by reiteration, arouse some attention in so far as they may point out a way of making the chemical engineer of the future a larger, broader and more influential man than he is to-day, and one who will occupy a position in the community of as great importance as the leaders of the other great professions.

CLIFFORD RICHARDSON

THE MECHANISM OF HEREDITY[1]

HEREDITY is to-day the central problem of biology. This problem may be ap-

[1]Address of the vice-president and chairman of Section F, Zoology, American Association for the Advancement of Science, Chicago meeting, 1907–8.